IoT-Aware Hybrid Intelligent Safety-Driven Vehicle-Pedestrian Traffic Control: Conceptual Framework

M. B. Soroyewun
Computer Science Department,
Ahmadu Bello University,
Zaria, Kaduna State, Nigeria
delemike@gmail.com

A. A. Obiniyi
Computer Science Department,
Ahmadu Bello University,
Zaria, Kaduna State, Nigeria
aaobiniyi@gmail.com

S. B. Junaidu
Computer Science Department,
Ahmadu Bello University,
Zaria, Kaduna State, Nigeria

E. A. Adedokun
Computer Engineering Department,
Ahmadu Bello University,
Zaria, Kaduna State, Nigeria

Abstract— *Internet of Things (IoT) is an emerging and disruptive technology that is impacting almost every area of human existence with connected things. Intelligent traffic control system (ITCS) is a subset of Intelligent Transportation System (ITS), which focuses more on managing road traffics in a smart, safe and efficient manner close to human reasoning but expected to overcome perceivable human limitations using Artificial Intelligence (AI). Current researches that considered vehicle-pedestrian traffic control identify the need for pedestrian safety by using single intelligence method and analyzing crash data without factoring prolonged pedestrian delay, complete/relevant weather conditions and period of the day into the reasoner when providing solution to vehicle-pedestrian crashes. This paper proposes a conceptual framework that comprises vehicular pedestrian modules, IoT-aware vehicle-pedestrian-weather sensor modules and a controller with hybrid neuro-fuzzy intelligence for the purpose of enhancing pedestrian safety.*

Keywords— ***Neural Network; Fuzzy Logic; Vehicle-Pedestrian traffic control; IoT-Aware; Hybrid Intelligence***

I. Introduction

Internet of Things (IoT) as an emerging and disruptive technology has begun impacting almost every area of human existence with connected things from business, agriculture, energy, social life to transportation management. Intelligent traffic control system (ITCS) is a subset of Intelligent Transportation System (ITS), which focuses more on managing road traffics in a smart, safe and efficient manner close to human reasoning but expected to overcome perceivable human limitations using Artificial Intelligence (AI).

In recent times, vehicular and pedestrian traffic controls have posed great challenges especially at busy junctions and roundabouts during rush hours. Everyone is a pedestrian as walking is still the preferred mode of transportation for many but the safety of the pedestrian is still of greater concern [1]. Most pedestrian accidents in urban areas occur at intersections and roundabouts because of the high concentration of vehicles and pedestrians at these locations [2] [3]. Available statistics showed that in 2015, there were 5,376 pedestrians killed and an estimated 70,000 injured in traffic crashes in the United States while a total of 5,295 traffic crashes had one or more pedestrian fatalities. On the average, a pedestrian was killed every 1.6 hours and injured every 7.5 minutes in traffic crashes [4]. According to [5], more than 270,000 pedestrians lose their lives on the world's roads annually, accounting for 22% of the total 1.24 million road traffic deaths while the proportion of pedestrians killed is highest in Africa (38%) and lowest in South-East Asia (12%). Hence, the capacity to respond to pedestrian safety should be an important consideration to prevent pedestrians' road traffic injuries and deaths. As at 2017, the number of pedestrian fatalities in the U.S. held steady with nearly 6,000 pedestrians killed that year. Ironically, this high rate of pedestrian deaths comes as deaths from other types of traffic fatalities are dropping. For instance, pedestrian deaths increased by 27 percent from 2007 to 2016, while other types of traffic deaths dropped by 14 percent [6].

Intelligent traffic control systems research outputs have helped in some ways to reduce road accidents but very few focused-on safeties of pedestrians. Current researchers have identified lack of adequate pedestrian facilities, prolonged pedestrian waiting time, human factors (non-compliance drivers and pedestrians) and considerations for vehicular traffic without corresponding attention to pedestrian traffic as important factors [7]. According to [4], averagely 6,000 people are killed and over 445,000 people are injured in weather-related crashes each year. Weather conditions and period of the day have also been recognized as major reasons for pedestrian fatalities but all of these have not been factored into the proffered solution. Hence, incorporating IoT for smart sensing of complete/relevant weather conditions and using hybrid neuro-fuzzy intelligent controller in Intelligent Traffic Control System can enhance the accuracy and efficiency of the intelligent system and further enhance the safety of the pedestrian without sacrificing vehicular efficiency.

A review of related literature as indicated in section III shows that past studies are primarily focused on the use of fuzzy logic designs for intelligent vehicular traffic control at intersections to reduce congestion without consideration for pedestrian safety. A few who focused on pedestrian safety did not use hybrid intelligence method and IoT technologies [7]. More so, few who studied hybrid intelligence for congestion reduction did not incorporate IoT and did not consider pedestrian safety [8] [9] while [10], [11], [12] focused on IoT in traffic and vehicle monitoring applications without consideration for pedestrian safety. This paper considers a conceptual framework for enhancing the pedestrian safety using hybrid neuro-fuzzy based intelligent traffic control system in IoT-aware architecture with consideration for complete but relevant atmospheric or weather conditions (rain, harmattan, heat, wind or rain, no rain but cold, no rain but hot, no rain but windy) and period of the day (morning, afternoon and evening).

The rest of the paper is organized as follows. Section II introduces IoT and Intelligent Transportation Systems, IoT Architecture and Sensors. Section III considers the related works while Section IV presents the conceptual framework for IoT-aware hybrid intelligent traffic control system. Section V looks at the materials and methods of the research. Section VI concludes with the conclusion and future work of the research.

II. IOT AND INTELLIGENT TRANSPORTATION SYSTEMS

The recent successes recorded in smart sensor technologies, wireless sensor networks and Internet of Things (IoT) researches have triggered a whole lot of efforts in dynamic monitoring and sensing of everything in the environment including vehicles and people. IoT has grown in recent years to a huge branch of research: Radio Frequency Identification (RFID), sensors and actuators as typical IoT devices are increasingly used as resources integrated into new value added applications of the Future Internet and are intelligently combined using standardized software services [13]. Hence, the goal of IoT is to enable things to be connected anytime, anyplace, with anything and anyone ideally using any path/network and any service. It is a new revolutionary concept translating into reality where objects or things make themselves recognizable and they obtain intelligence by making or enabling context related decisions due to the fact that they can exchange information about themselves and can access aggregated information made available by other things [14]. Summarily, IoT is the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment and the array of efficient wireless protocols, improved sensors, and cheap processors combined with necessary management and application software [15].

Intelligent transportation system (ITS) is an advanced application which aims to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated and smarter use of transport network [16]. As stated earlier, intelligent traffic control system (ITCS) is a subset of ITS, which focuses more on managing road traffics in a smart, safe and efficient manner close to human reasoning but expected to overcome perceivable human limitations such as fatigue and misjudgment or partiality.

In [17], the paper focused on an urban IoT system used to build intelligent transportation system. The work presented a real-time traffic monitoring system to solve the problem of real time traffic controlling and monitoring. Two types of sensors were employed in the work; parking sensors and roadway sensors. The information obtained from the sensors is passed to the sensor management systems. Sensors identify the vacant parking spaces and send the information to the central server. More so, smart phone app requests for a parking space and the vehicle is directed to the available parking space. At the same time the parking fee is paid directly through the mobile app. However, the work did not consider pedestrian safety.

Reference [18], in their work, designed and implemented an IoT based remote monitoring for Asthma patients. The work used the result of the survey from specialists on Asthma chronic disease to design a prototype IoT Asthma monitoring system made up of a heart pulse sensor controlled by ESP8266 Wi-Fi Module. The data collected from the sensor was wirelessly passed to the ESP8266 in real time which then sent same to the cloud using HTTP protocol. MySQL database was used to store the received readings in the cloud. Medical personnel could then browse the webpage written in PHP to monitor live update of patient condition. Packet tracer was used to simulate the network in order to verify its operation. Their work neither considered Intelligent Transportation nor pedestrian safety.

Reference [19], worked on IoT-based Smart Museum for a new interactive cultural experience. The work aimed to design and validate an indoor location-aware architecture able to improve the user experience in a museum through wearable devices by interacting with an IoT-based smart environment, to act as museum guides, so as to provide a real interactive cultural experience. The focus of the work is mainly IoT-based Smart Museum without considering Intelligent Transportation and pedestrian safety.

A. IoT Architectures

Since IoT is currently undergoing dynamic development, there is no single consensus on architecture for IoT, hence different architectures have been proposed by different authors. However, there are currently two most common architectures for the IoT. These are 3-Layer and 5-Layer Architectures as shown in figure 1.

The most basic architecture is 3-layer architecture comprising the perception, network and application layers while the 5-layer consists of the perception, transport, processing application and business layers. The three-layer architecture closely explains the main idea of the Internet of Things, but it is not sufficient for research on IoT because current researches more often than not focus on finer aspects of the Internet of Things. A comprehensive treatment of each component of 3-layer and 5-layer architecture is done in [20].

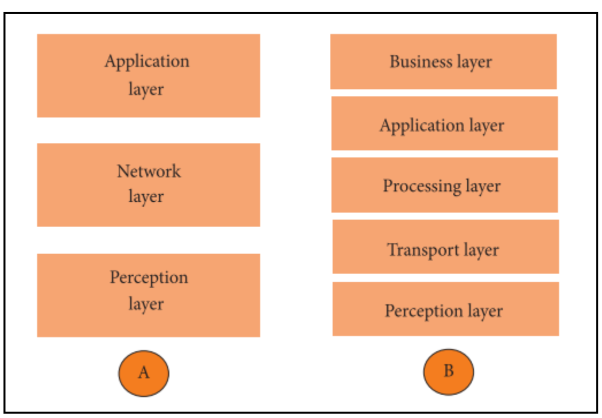

Figure 1: IoT Architecture (A: 3-Layer) (B: 5-Layer) [20]

B. IoT-Aware Sensors/Actuators

The designs of Intelligent Traffic Control Systems have largely benefited from the use of inductive sensors/actuators without IoT-awareness. IoT-aware sensor/actuator modules using Arduino or Raspberry Pi will introduce smartness into
the framework. Hence, incorporating IoT in Intelligent Transportation System will enhance the accuracy and efficiency of the intelligent system.
Sensors are actually the entry points to any IoT-based system as shown in figures 2 and 3. There are a number of IoT sensors/actuators available now such as rain/moisture, temperature, power, humidity, proximity, force, occupancy, acoustic, light, wind speed and strain sensors.

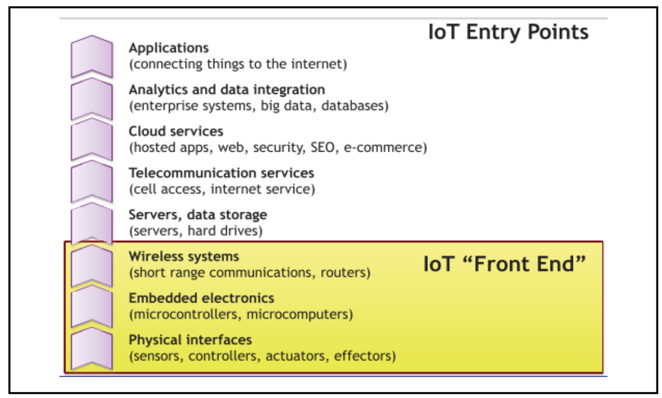

Figure 2: IoT entry points [21]

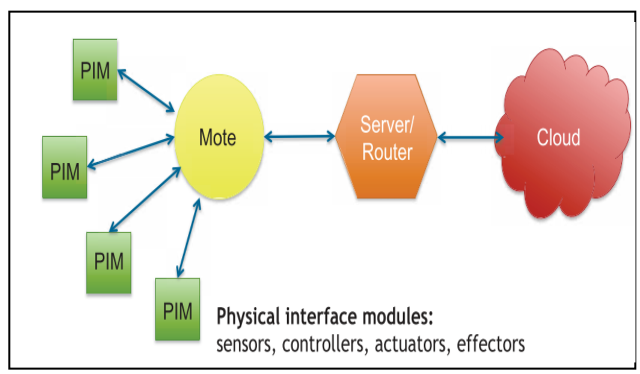

Figure 3: Physical Interface Modules [21]

III. RELATED WORKS

In [22], the authors worked on Dynamic Traffic Light Sequence Algorithm Using RFID for traffic congestion and tidal flow management in modern urban areas, which have caused much frustration and loss of man hours. The intelligent RFID traffic control system developed has circumvented or avoided the problems that usually arise with systems such as those, which use image processing and beam interruption techniques. However, pedestrian safety and weather conditions were not considered in the proposed solution.

The authors in [23] researched on Intelligent Traffic Light Control System for Isolated Intersection Using Fuzzy Logic. Their work designed and implemented an intelligent traffic lights control system based on fuzzy logic technology. They developed a software using MATLAB to simulate the situation of an isolated traffic junction based on fuzzy logic. The simulation results showed that the fuzzy logic controller has better performance and is more cost effective than fixed time controller. Also, their work neglected pedestrian safety and used single intelligence (fuzzy logic).

The work of [24] focused on design and construction of prototype Automatic Intelligent Traffic Control System for regulating traffic involving Ambulance, Priority vehicles (like VIP cars, police jeeps) and other vehicles in order to reduce traffic congestion. The work was majorly hardware-based and did not consider pedestrian safety.

In [8], fuzzy neural network was used for real time traffic signal control at an isolated intersection in order to improve the vehicular throughput and minimize delays without considering weather conditions and pedestrian safety. Three input variables of the fuzzy controller were used in the design; the number of approaching vehicles in the current green phase (denoted by Avi), number of queuing vehicles in the current green phase (denoted by qgi) and the number of queuing vehicles in the current red phase (denoted by qri). The output variable is the extended time in the current green phase (expressed by Δti). It was noted that pedestrian safety was not factored in.

The work in [9] introduced a hybrid algorithm that used Fuzzy Logic Controllers (FLCs) and Genetic Algorithms (GAs) to improve the performance of traffic signal controllers, in order to reduce the traffic jams and the waiting time. The simulation results yielded by the hybrid algorithm showed an improvement of up to 34% in the performance with respect to a standard traffic signal controller, Conventional Traffic Signal Controller (CTC), and up to 31% in the comparison with a traditional logic controller, such as FLC. However, pedestrian safety was neglected outrightly and weather situation was not considered.

However, [7] focused on incorporation of pedestrian crossing variables into vehicular traffic control using fuzzy logic. The impact of pedestrian delay and total pedestrian were part of consideration for signal time allocation. The result of their work proved that pedestrian delay has significant contribution to traffic control systems to enhance safety of pedestrians.

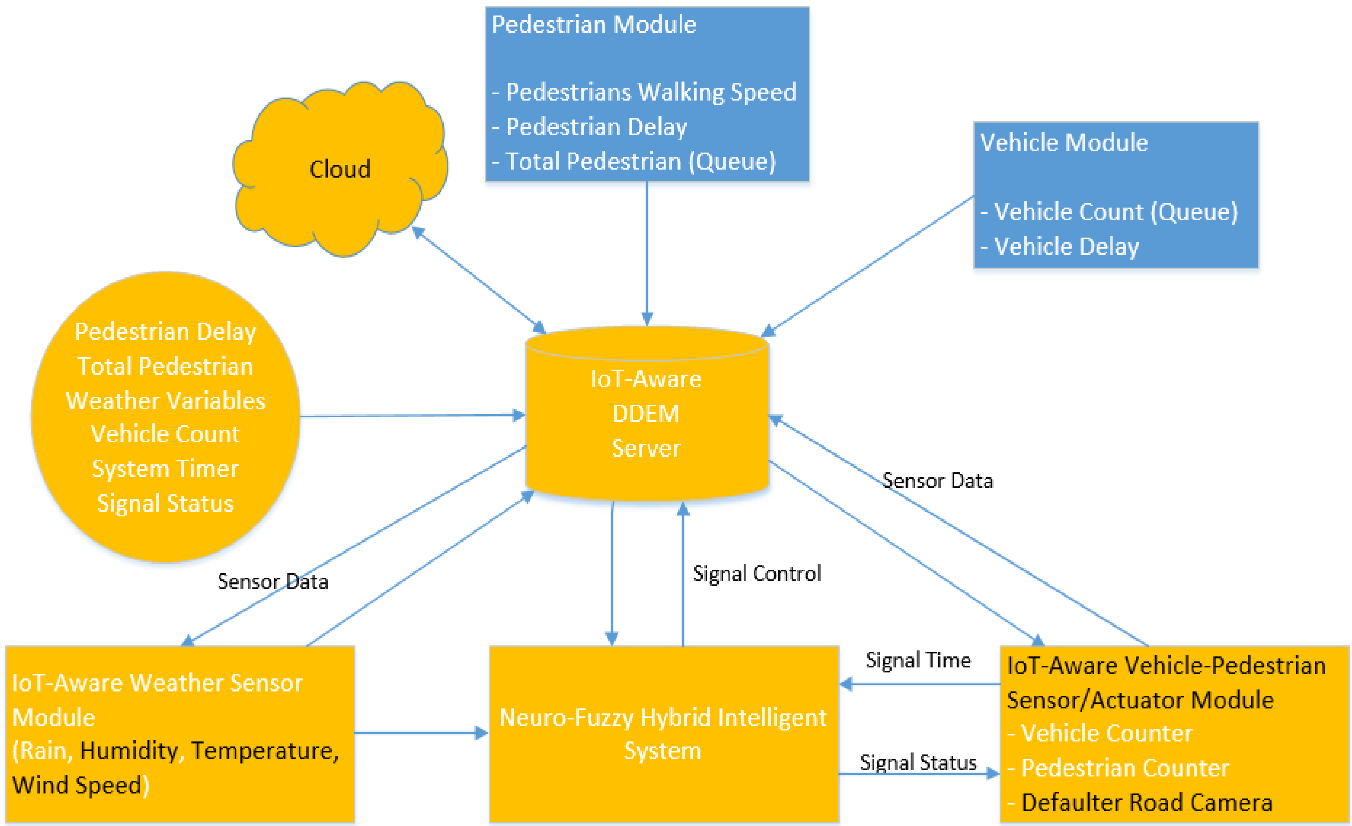

Figure 4: Conceptual framework for the proposed Enhanced Pedestrian Safety-Driven IoT- Aware Hybrid Intelligent traffic control system

From the evaluation of the system, the Fuzzy Intelligent Traffic Control (FITC) achieved an average improvement of 53.19% over fixed time traffic control, FITC Pedestrian delay improved by 13.13% over fixed time and a potential crash rate reduction from 2.83% to 0.37% using crash data obtained from Federal Road Safety Corps (FRSC) records. Their work employed single intelligence algorithm and only two weather variables (rain and no rain) were considered without incorporating IoT-awareness and period of the day (morning, afternoon and evening) into the fuzzy logic controller (also called the reasoner).

This research will seek to improve on their work by using hybrid neuro-fuzzy intelligence, with both junction and circular intersections (roundabout), complete but relevant weather conditions (rain, harmattan, heat and wind) and period of the day while incorporating IoT-aware sensors/actuators module for enhanced pedestrian safety.

IV. CONCEPTUAL FRAMEWORK FOR IOT-AWARE HYBRID INTELLIGENT TRAFFIC CONTROL SYSTEM

The conceptual framework presented in figure 4 is a diagrammatical representation of the flow of information between the different parts of the framework.
The Dynamic Data Exchange Module (DDEM) receives inputs from road network as indicated by the arrows, this information is passed to Neuro-Fuzzy Hybrid intelligent system for fuzzification and subsequent neural network training with self-learning. The actual signal time generated by the intelligent system is passed through the DDEM to the IoT-actuator module to control the traffic. The resulting data can be further stored in the cloud for future analysis.

V. MATERIALS AND METHODS

Fuzzy logic permitted the development of models of physical processes by allowing linguistic and inexact data to be manipulated as a useful tool in designing signal timings. More so, the linguistic control strategy that is decided by “if-then-else” statement can be converted into a control algorithm using fuzzy logic. The design of a fuzzy signal controller needs an expert knowledge and experience of traffic control in formulating the linguistic protocol, which generates the control input to the traffic signal control system [8].

Figures 5 and 6 show the fuzzy logic design in both MATLAB and fuzzyTECH environment, while Tables 1 and 2 indicate the fuzzy logic input, output variables and the linguistic values. In addition, Figures 7, 8 and 9 show the fuzzy rules and the neuro-fuzzy model designs for the framework. A total of 768 fuzzy rules were formed by multiplying the total number of linguistic variables of the 5-input variables (4*4*4*4*3=768) which were optimized by the neural network model to remove redundant rules.

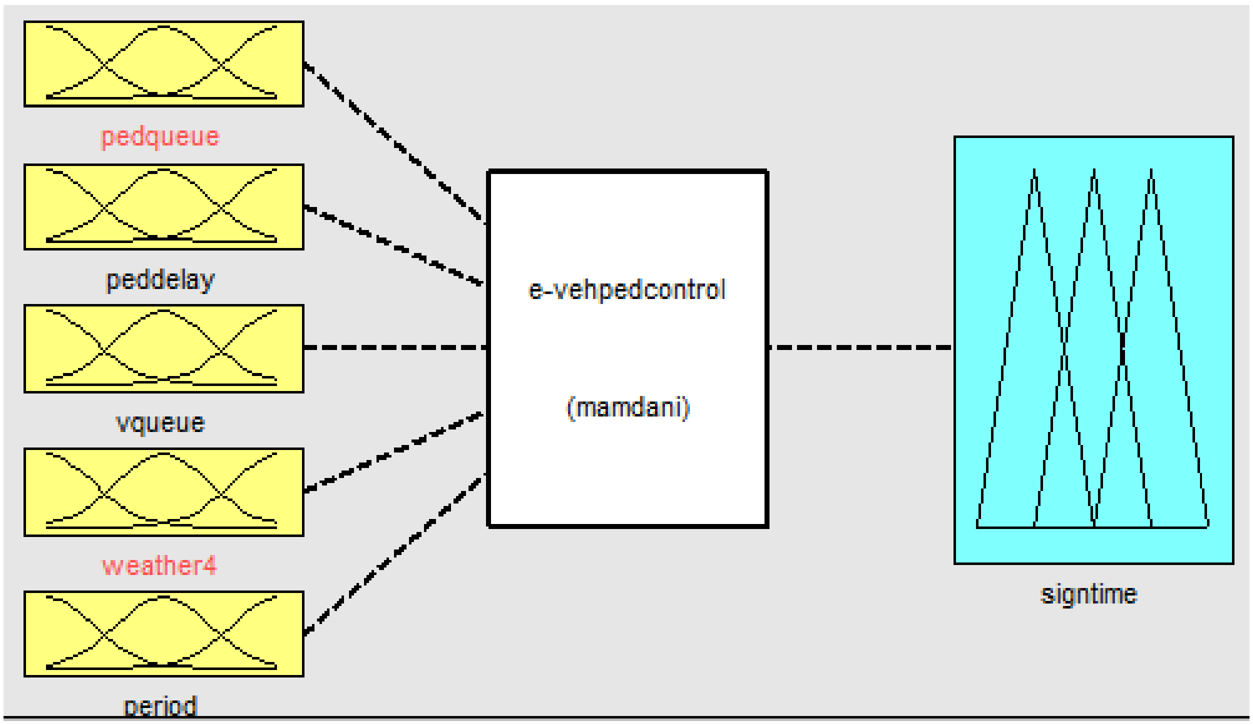

Figure 5: Fuzzy Logic Inference System Design in MATLAB

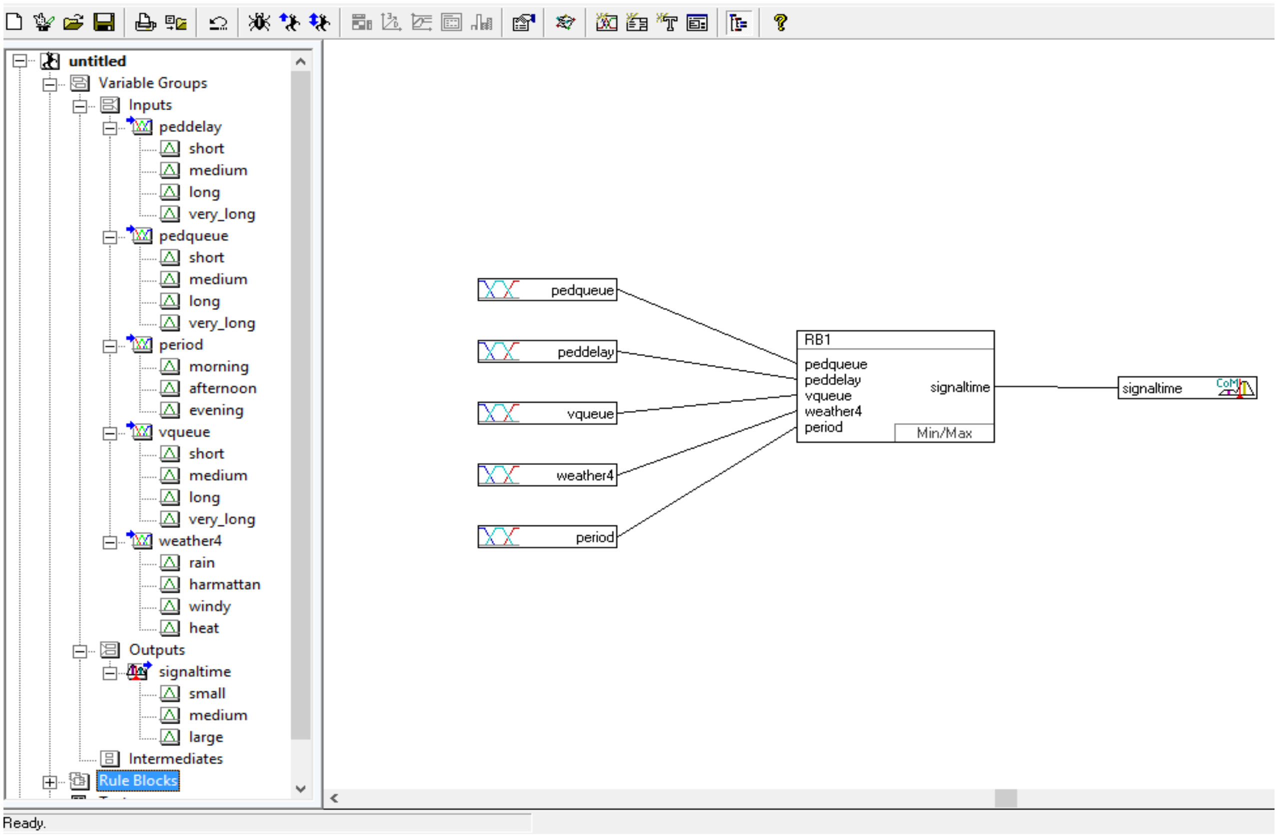

Figure 6: Fuzzy Logic Inference System Design in FuzzyTECH

Artificial neural networks (ANNs) (learning systems) and expert system (knowledge-based systems) have been extensively explored as approaches for decision making. While the ANNs compute decisions by learning from successfully solved examples, the expert systems rely on a knowledge base developed by human reasoning for decision making.

An important aspect in intelligent system design is decision explanation, which involves supplying a coherent explanation of its decisions [25]. This is required for acceptability of the solution and correctness of the reasoning process by evaluating the trace generated by the inference engine or by analyzing the rule base. Also, in learning system such as ANNs, knowledge is represented in the form of weighted

connections, making decision tracing or extraction difficult. The resulting Neuro-Fuzzy approach has the advantages of both fuzzy expert system (fuzzy reasoning) and artificial neural network (self-study) [8].

The work will be fully implemented using a microscopic traffic simulator, IoT simulator and MATLAB Fuzzy Logic Designer and MATLAB programming.

Table 1: Fuzzy Logic Input Variables and Linguistic values

Pedqueue		Peddelay		Vqueue		Weather		Period	
Range	**Linguistic value**	**Range (sec)**	**Linguistic value**	**Range**	**Linguistic value**	**state**	**Linguistic value**	**State**	**Linguistic value**
1 – 42	Short	1 – 60	Short	1 - 20	Short	0.0 – 0.4	Rain	6am - 11.59am	Morning
30 – 80	Medium	35 –120	Medium	7 - 42	Medium	0.2 – 0.6	Harmattan	12noon - 5.59pm	Afternoon
75 - 120	Long	75 – 180	Long	32 - 50	Long	0.4 – 0.8	Wind	6pm- 9pm	Evening
95- 160	Very Long	125 - 300	Very Long	45 - 80	Very Long	0.6 – 1.0	Heat		

Table 2: Fuzzified output variable

Signal Time Membership Function(sec)	
Short	**0 - 30**
Medium	**10 - 50**
Large	**40 – 60**

#	IF pedqueue	peddelay	vqueue	weather4	period	THEN DoS	signaltime
1	short	short	short	rain	morning	1.00	small
2	short	short	short	rain	afternoon	1.00	small
3	short	short	short	rain	evening	1.00	medium
4	short	short	short	harmattan	morning	1.00	small
5	short	short	short	harmattan	afternoon	1.00	small
6	short	short	short	harmattan	evening	1.00	small
7	short	short	short	windy	morning	1.00	small
8	short	short	short	windy	afternoon	1.00	small
9	short	short	short	windy	evening	1.00	small
10	short	short	short	heat	morning	1.00	small
11	short	short	short	heat	afternoon	1.00	small
12	short	short	short	heat	evening	1.00	small
13	short	short	medium	rain	morning	1.00	small
14	short	short	medium	rain	afternoon	1.00	small
15	short	short	medium	rain	evening	1.00	medium
16	short	short	medium	harmattan	morning	1.00	small
17	short	short	medium	harmattan	afternoon	1.00	small
18	short	short	medium	harmattan	evening	1.00	medium
19	short	short	medium	windy	morning	1.00	small
20	short	short	medium	windy	afternoon	1.00	small
21	short	short	medium	windy	evening	1.00	small
22	short	short	medium	heat	morning	1.00	small
23	short	short	medium	heat	afternoon	1.00	small
24	short	short	medium	heat	evening	1.00	small
25	short	short	long	rain	morning	1.00	small
26	short	short	long	rain	afternoon	1.00	medium
27	short	short	long	rain	evening	1.00	medium
28	short	short	long	harmattan	morning	1.00	small
29	short	short	long	harmattan	afternoon	1.00	small
30	short	short	long	harmattan	evening	1.00	medium

Design Mode

Figure 7: A snapshot of the Fuzzy Rules 1 - 30 for the 5- input and 1- output Design

#	IF pedqueue	peddelay	vqueue	weather4	period	THEN DoS	signaltime
740	very_long	very_long	medium	windy	afternoon	1.00	large
741	very_long	very_long	medium	windy	evening	1.00	large
742	very_long	very_long	medium	heat	morning	1.00	medium
743	very_long	very_long	medium	heat	afternoon	1.00	medium
744	very_long	very_long	medium	heat	evening	1.00	large
745	very_long	very_long	long	rain	morning	1.00	large
746	very_long	very_long	long	rain	afternoon	1.00	large
747	very_long	very_long	long	rain	evening	1.00	large
748	very_long	very_long	long	harmattan	morning	1.00	large
749	very_long	very_long	long	harmattan	afternoon	1.00	large
750	very_long	very_long	long	harmattan	evening	1.00	large
751	very_long	very_long	long	windy	morning	1.00	medium
752	very_long	very_long	long	windy	afternoon	1.00	large
753	very_long	very_long	long	windy	evening	1.00	large
754	very_long	very_long	long	heat	morning	1.00	medium
755	very_long	very_long	long	heat	afternoon	1.00	large
756	very_long	very_long	long	heat	evening	1.00	large
757	very_long	very_long	very_long	rain	morning	1.00	large
758	very_long	very_long	very_long	rain	afternoon	1.00	large
759	very_long	very_long	very_long	rain	evening	1.00	large
760	very_long	very_long	very_long	harmattan	morning	1.00	large
761	very_long	very_long	very_long	harmattan	afternoon	1.00	large
762	very_long	very_long	very_long	harmattan	evening	1.00	large
763	very_long	very_long	very_long	windy	morning	1.00	large
764	very_long	very_long	very_long	windy	afternoon	1.00	large
765	very_long	very_long	very_long	windy	evening	1.00	large
766	very_long	very_long	very_long	heat	morning	1.00	medium
767	very_long	very_long	very_long	heat	afternoon	1.00	large
768	very_long	very_long	very_long	heat	evening	1.00	large
769							

Figure 8: A snapshot of the Fuzzy Rules 740-768 for the 5- input and 1- output Design

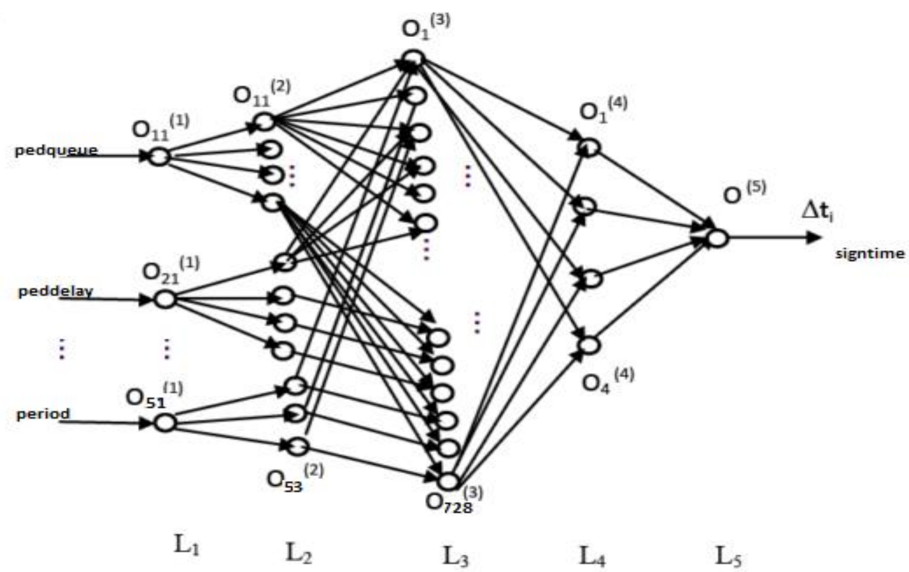

Figure 9: Neuro-Fuzzy Model for the Framework

VI. CONCLUSION AND FUTURE WORK

The existing research efforts in IoT that focused on Intelligent Traffic Control System (ITCS) did not incorporate pedestrian safety while researches on ITCS that considered pedestrian's safety identify the need for safety by using single intelligence method and analyzing crash data without factoring prolonged pedestrian delay, complete/relevant weather conditions and period of the day into the control system when providing solution to vehicle-pedestrian crashes. This work considers the current research efforts in intelligent traffic control systems and IoT with focus on pedestrian-vehicular traffic and safety. In particular, a conceptual framework has been developed which comprises IoT-aware neurofuzzy-based intelligent pedestrian-vehicle traffic control system for enhancing the safety of the pedestrians at busy intersections and rush hours without sacrificing vehicular efficiency. The framework will be fully implemented using a microscopic traffic simulator, IoT simulator, MATLAB Fuzzy Logic Designer and MATLAB programming.

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